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FOUNDRY ALLOY

The present invention relates to an improved foundry alloy and to a method of producing an improved foundry alloy. In particular, the improved foundry alloy is an aluminium-based alloy.

Primary metal based foundry alloys are largely used for structural or safety type applications where there is a requirement for high and consistent mechanical properties. The majority of components made from aluminium foundry alloys are made from hypoeutectic aluminium-silicon-magnesium alloys containing a nominal silicon level of 7% by weight (601 and 603 designations). In simple terms these alloys are a composite of hard, discontinuous silicon particles and large, brittle iron intermetallics embedded in a ductile aluminium matrix.

There are three registered Australian compositions for strontium-modified aluminium - 7% silicon alloys. These are given in Table 1. The magnesium content of the alloys covers the range 0.25 to 0.4 wt% (601 alloys) and 0.45 to 0.7 wt% (603 alloys). The addition of magnesium allows castings to be heat treated to form magnesium silicide precipitates. These harden the matrix of the alloy to obtain the desired combination of strength and ductility.

Table 1. Registered alloy composition for strontium modified 601/603 type foundry alloys

Alloy Code	Si	Fe	Cu	Mn	Mg	Zn	Ti	Other Each	Other Total	Al
AC601	6.5-7.5	0.20	0.05	0.05	0.30-0.40	0.05	0.20	0.05	0.15	Rem
CC601	6.5-7.5	0.20	0.05	0.05	0.25-0.35	0.05	0.20	0.05	0.15	Rem
AC603	6.5-7.5	0.15	0.05	0.03	0.45-0.7	0.05	0.20	0.05	0.15	Rem

♣ Compositions in weight percent. Compositions indicate a maximum unless a range is given

The main impurity found in these alloys is iron. The iron solidifies from the eutectic liquid into a number of brittle phases.

The two major iron-containing phases found in these alloys are the π phase ($Al_8Si_6Mg_3Fe$) which is the predominant phase formed in high Mg content alloys and the β phase (Al_5SiFe) which forms in low magnesium content alloys. The π phase forms into a script morphology while the β phase is less voluminous and forms into acicular plates. Both phases are detrimental to mechanical properties. High Mg contents (ie greater than 0.6 wt% Mg) are desirable to provide higher strength, but the presence of π phase at high Mg contents causes the ductility of the alloys to unfavourably decrease.

Conventional theories on the micro-mechanics of failure of premodified 601 and 603 alloys state that the iron rich intermetallic phases are critical in determining the fracture toughness as the silicon particles are small and round. Increases in the magnesium content of these alloys increase the amount of the π phase, which has a negative impact on the ductile properties of the alloys.

Further, as some magnesium is contained in the π phase, the maximum volume fraction of magnesium silicide precipitates cannot be obtained. Thus, the alloys do not achieve the maximum possible strength consistent with their magnesium content.

Also, as the magnesium content of an alloy increases the magnesium content of the π phase may change leading to even greater volume fractions of the phase for a given Fe content.

It is thus concluded that the overall quality of

an alloy, as given by the quality index, decreases as
increasing volume fractions of the π phase forms at
increased magnesium contents. The quality index is given
by the formula:

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Q.I. = UTS + 150 log$_{10}$ E

where:

Q.I. = Quality Index (Mpa)
10   UTS = Ultimate Tensile Strength (Mpa)
E = Elongation at Fracture (%)

Attempts have been made to eliminate the π phase
and thus remove its detrimental impact on mechanical
15 properties.

By way of example, beryllium additions can be
used to precipitate the iron impurity as part of the
BeSiFe$_2$Al$_8$ phase. This beryllium-containing phase forms in
20 preference to the π phase, leading to alloys with improved
mechanical properties. Unfortunately, there are serious
health hazards associated with using beryllium.
Consequently, beryllium modification is not widely
practised and the deleterious effect of the π phase on
25 alloy quality remains.

Other attempts to modify the iron-containing
phases, for example by using Mn, have been tried in
secondary alloys but have not been used in primary alloys.
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It is an object of the present invention to
provide an improved foundry alloy.

In accordance with the present invention this
35 object is achieved by an alloy having a microstructure in
which β phase that forms during heat treatment as a
transformation product of π phase is the sole or

predominant iron-containing phase. The reduction in π phase results in an improvement in ductility. Moreover, the β phase that forms as the transformation product has a fine structure that improves ductility. Further, the

5   reduction in π phase means that there are higher levels of Mg in solution which are available for precipitation during ageing to improve the strength of the alloy.

In a first aspect, the present invention provides

10   an alloy which comprises:

Si	:	6.5 - 7.5 wt%
Fe	:	up to 0.20 wt%
Cu	:	up to 0.05 wt%
Mn	:	up to 0.05 wt%
Mg	:	0.35 to 0.50 wt%
Zn	:	up to 0.05 wt%
Ti	:	up to 0.20 wt%

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20   Balance : Al and other components, the other components comprise a total of not more than 0.15 wt% and any single component of the other components does not exceed 0.05 wt%, the alloy having a microstructure which includes a primary aluminium-containing matrix and one or

25   more iron-containing phases dispersed in the matrix, and wherein the sole or predominant iron-containing phase is β phase that formed as a transformation product of π phase.

It is preferred that the dendrite arm spacing of

30   the matrix be 10-45μm.

Where there is more than one iron-containing phase, preferably the iron-containing phases also include π phase.

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Preferably, the iron-containing phases include π phase in an amount up to 30 vol% of the iron-containing

phases. The amount of π phase may be higher if the Mg content is in the upper end of the range.

5   The Mg content of the alloy is preferably 0.40-0.45 wt%. Within this Mg range, the alloy is a variant of the 601/603 type foundry alloy. It has been realised by the applicant that close control of the magnesium content to be between 0.40 and 0.45 wt% can lead to an increase in alloy quality and improved mechanical properties. In
10   particular, when the magnesium content is controlled to be between 0.40 and 0.45 wt% the variation in alloy quality for a small change in magnesium level is minimal. Thus, the consistency in the mechanical properties of the alloy is maximised.

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The present invention also provides a method for manufacturing an alloy article.

In a second aspect, the present invention
20   provides a method for manufacturing an alloy article which comprises:

(a)   providing a melt having a composition of:

Si   :   6.5 - 7.5 wt%
25   Fe   :   up to 0.20 wt%
Cu   :   up to 0.05 wt%
Mn   :   up to 0.05 wt%
Mg   :   0.35 to 0.50 wt%
Zn   :   up to 0.05 wt%
30   Ti   :   up to 0.20 wt%

Balance : Al and other components, the other components comprising a total of not more than 0.15wt% and any single component of the
35   other components not exceeding 0.05 wt%,

(b)   casting said melt and solidifying a casting

at a cooling rate that produces a
microstructure of an aluminium-containing
matrix and π and β iron-containing phases
dispersed in the matrix;

(c)   solution heat treating the casting to at
        least partially transform π phase to β
        phase; and

(d)   quenching the casting to form the alloy
        article.

        It is preferred that the cooling rate be
sufficient to produce a dendrite arm spacing in the matrix
in the casting of 10-45μm.

        Preferably, the sole or predominant iron-
containing phase in the alloy article is β phase.

        Where there is more than one iron-containing
phase in the alloy article, preferably the iron-containing
phases also include π phase. More preferably, the iron-
containing phases in the alloy article include π phase in
an amount of up to 30 vol% of the iron-containing phases.
Higher levels of π phase may be present if the Mg content
is at the upper end of the above range.

        It is preferred that the step of solidifying the
casting produces iron-containing phases that include a
substantial proportion of the π phase and the subsequent
solution heat treatment step is effective to convert at
least some and preferably a majority of the π phase to β
phase to give a microstructure in the alloy article that
includes iron-containing phases which are predominantly β
phase.

        The melt prior to casting may be at a temperature

above the liquidus temperature of the alloy, with the melt having sufficient superheat to fill the mould, that is at a temperature of 680-720°C.

5   The solution treatment of the casting may be carried out at any suitable temperature and for any suitable time to achieve a desired level of transformation of π phase β phase. In any given situation, the selection of the parameters of temperature and time will depend on

10   variables, such as the concentrations of magnesium and other elements in the casting. By way of example, the applicant has found that for castings having a Mg concentration of 0.5 wt%, solution treatment at 540°C for 2 or more hours produced desired levels of transformation of

15   π to β phase

       After the solution heat treatment, the casting is preferably quenched, more preferably quenched in hot water, such as hot water having a temperature of 70-80°C.

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       After quenching, the alloy article is cooled to room temperature and optionally subjected to an ageing heat treatment.

25   The ageing heat treatment may include heating the alloy article to a temperature of 140-170°C and holding at that temperature for 1-10 hours. After the ageing heat treatment, the alloy article may be air cooled to room temperature.

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       Results to support the present invention are given in Figure 1, in which plots of typical response surfaces derived from experimentally determined quality index data are shown. The three surfaces correspond to

35   alloys that were cast at different solidification rates and thereafter solution treated and aged. Solidification rate is commonly measured by the as-cast dendrite cell size or

secondary dendrite arm spacing (DAS) but other methods
exist. The results here use secondary dendrite arm spacing
to indicate solidification rate, with a small dendrite arm
spacing corresponding to a high solidification rate.

It can be seen from Figure 1 that:

(i)   at the high solidification rate ($\approx$20μm DAS)
       the alloy quality peaks at a magnesium level
       of 0.45-0.50 weight percent;

(ii)   at the intermediate solidification rate
       ($\approx$40μm DAS) the quality peaks at a magnesium
       level of 0.35-0.40 weight percent; and

(iii) at the low solidification rate ($\approx$60μm DAS)
       the quality maximum occurs at a magnesium
       level of 0.25-0.30 weight percent.

Further, it can be seen from Figure 1 that the
magnesium level for the peak quality is independent of the
iron level for the iron levels examined. Also, the rate of
change of the response surfaces with magnesium is least
near the peak in quality index. This means that the alloys
at the peak are less sensitive to changes in magnesium than
other alloys. The peak quality from Figure 1 corresponds
well with microstructural evidence for small amounts of π
phase in the alloy. By increasing the magnesium content of
the alloy, it can be seen that in some circumstances
improved quality results.

It should be noted that the present invention
works best with those casting designs or casting methods
which produce high solidification rates ($\leq$45μm DAS), such
as permanent mould, mould chill methods with sand, and
squeeze casting. Indeed, the trend in the automotive
industry is to move away from thick section, low

solidification rate (high DAS) castings towards lightweight
castings with thinner sections and higher solidification
rates (low DAS).

5   The common belief prior to the present invention
was that low magnesium levels produce high quality
castings. The results shown here confirm this to be true
at low solidification rates (Figure 1c). However, at
higher solidification rates, the magnesium contents covered
10   by this invention show, surprisingly, improved alloy
quality and therefore improved mechanical properties.

          Figures 2(a) to 2(c) are photomicrographs of
hypoeutectic alloys having a Si concentration of 7 wt% and
15   various Mg concentrations which were cast at the same
solidification rate (60μm DAS), solution treated, and aged.
Figure 2(d) is a photomicrograph of the as-cast alloy of
Figure 2(c), ie before heat treatment.

20   In Figure 2(a), the Mg content of the alloy is
higher than the Mg content of the alloy of the present
invention. The main phases shown in Figure 2(a) are
spheroidal silicon-containing phase and the iron-containing
π phase.

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          Figure 2(b) shows the microstructure of an alloy
containing less Mg than the alloy of the present invention.
The phases present include spheroidal silicon-containing
phase and iron-containing β phase. The β phase is present
30   as structures of high aspect ratio dispersed throughout the
matrix.

          Figure 2(c) shows the microstructure of an alloy
of the present invention. The phases include spheroidal
35   silicon-containing phases, a small amount of π phase and β
phase. The β phase is present as structures of high aspect
ratio clumped together. This is consistent with the β

phase being formed by transformation of π phase during heat treatment.

Figure 2(d) shows that prior to heat treatment the as-cast alloy of Figure 2(c) had regions of π phase. As is evident from Figure 2(c) these π phase regions were largely transformed to β phase during heat treatment.

The drive for alloys with improved mechanical properties stems from the major restraint that mechanical properties place on the design of the casting, or even if a cast alloy can be used to manufacture a certain component. The thickness of critical sections needs to be sufficiently large that the cast component can operate without failure. Mechanical properties of the alloys therefore limit the minimum weight of a cast component. Further, the thickness of sections of a casting will determine the time required for the casting to solidify. For certain casting methods, such as low pressure die casting, the production rate is often determined by the solidification rate as the casting machine is tied up until the casting has fully solidified. Finally, the solution treatment, quench rate and ageing treatment of a cast component may be tailored to its design so as not to induce unnecessarily high residual stresses. High residual stresses can cause distortion of the component requiring additional machining. The mechanical properties of the base alloy therefore affect all stages of manufacturing from design, to casting the component, heat treatment, machining, final weight and production rate.

The present invention therefore has the following more specific applications:

(i)   New markets for aluminium-7% silicon foundry alloys. Cast alloys generally have inferior mechanical properties but lower manufacturing costs compared to similar

components made from wrought alloys. The
high mechanical property requirements of
some components necessitates the use of
wrought alloys. The achievement of alloys
of the present invention which have higher
and more consistent mechanical properties
than conventional alloys may allow the use
of the alloy of the present invention to
replace wrought alloys, or other cast
alloys, for some components.

(ii) Cast components with thinner sections and
lower total weight. The improved and more
consistent mechanical properties of the
alloy of the present invention allows
components with thinner sections to be
designed and cast. Despite their thinner
sections, these components can still operate
without failure and will have a lower total
weight.

(iii) Cast components with an improved production
rate. Castings with thinner sections may
require less time to solidify. Production
equipment will then be tied up for less time
waiting for a component to solidify. The
production rate is thus increased.

(iv) Cast components with refined iron and
silicon intermetallic phases. The
solidification time of a casting strongly
determines the coarseness of the
microstructure. Components with thinner
sections and therefore higher solidification
rates (and lower solidification times) will
have a more refined microstructure. This
refining of the microstructure will provide

additional improvements to the mechanical
properties of a casting, independent of the
use of a superior alloy.

5   (v)   Cast components with reduced heat treatment
              time. Castings with thinner sections
              require less time to homogenise. Further,
              the time required for the casting to reach
              the solution treatment temperature or ageing
10   temperature will be less. This also
              benefits the production rate of components.

       (vi)   Cast components with increased quench rate.
              Thinner castings may quench more rapidly.
15   This may lead to improved mechanical
              properties as it suppresses the formation of
              magnesium-silicide precipitates during
              cooling. These improved properties are
              independent of any refinement of the
20   microstructure or the use of a superior
              alloy.

       It will be appreciated that the invention
described herein is susceptible to variation and
25 modifications other than those specifically described. It
is to be understood that the invention encompasses all such
variations and modifications that fall within its spirit
and scope.